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(51) INT CL[4]
G01B 11/00 // 11/24

(52) Domestic classification
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GB A 2107048 GB 1261924 WO 8404960
GB A 2034880

(58) Field of search
G1A

ERRATUM

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Front page Heading (71) Applicant
for Jolan Prof Mohamad,
read Jalan Prof. Mohamad,
for Kelurhan read Kelurahan

THE PATENT OFFICE
29 August 1986

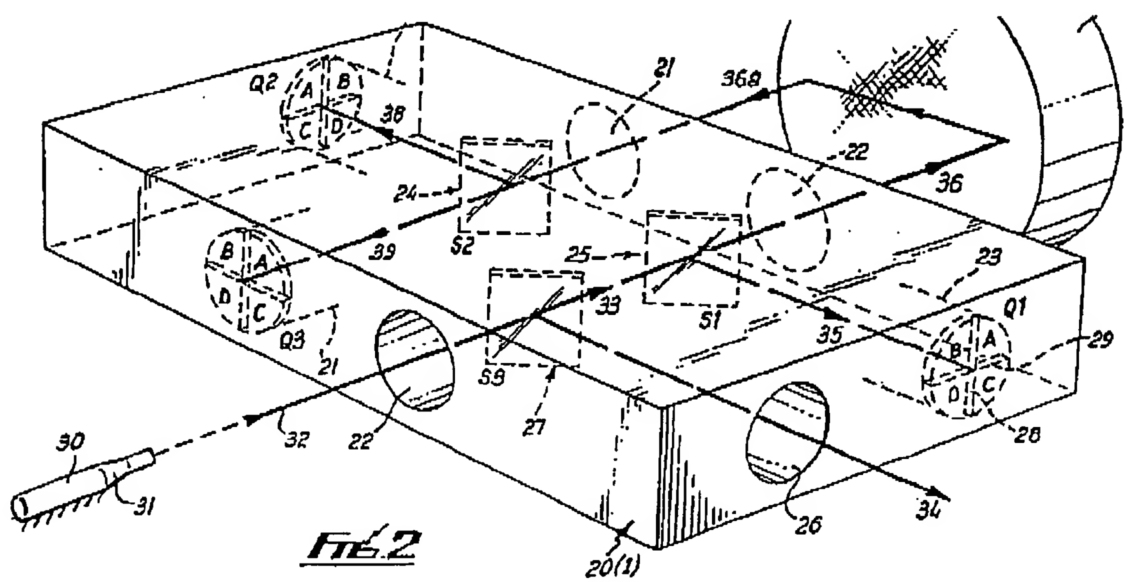

FIG.2

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(56) Documents cited
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GB A 2107048 GB 1261924 WO 8404960
GB A 2034880

(58) Field of search
G1A

(54) A device for use in assessing the position of a body

(57) The device is in the form of a block in which are mounted two parallel quadrant detectors Q1, Q2 at right angles to a third detector Q3. Parallel light 32 from a laser 30 is split by beam splitter S1 into beam 35 going to Q1 and beam 36 going via retroreflector 37 to beam splitter S2 producing beam 39 goig to Q3 and beam 38 going to Q2. Movement of the block relative to beam 32 produces signals from Q1, Q2, Q3 from which position errors can be calculated. Splitter S3 may send beam 34 to a second similar device. Three such devices can be used to provide position errors caused by movement in two orthogonal directions and by roll, pitch and yaw, relative to a datum. Errors in a third orthogonal direction are obtained using a laser interferometer.

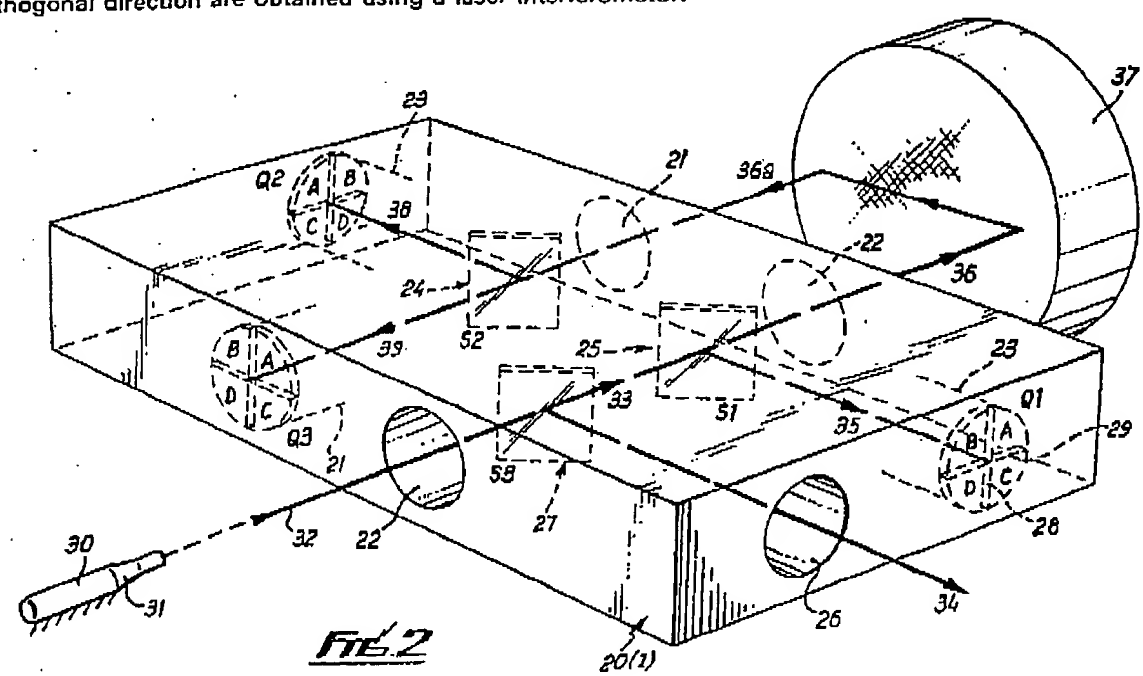

FIG. 2

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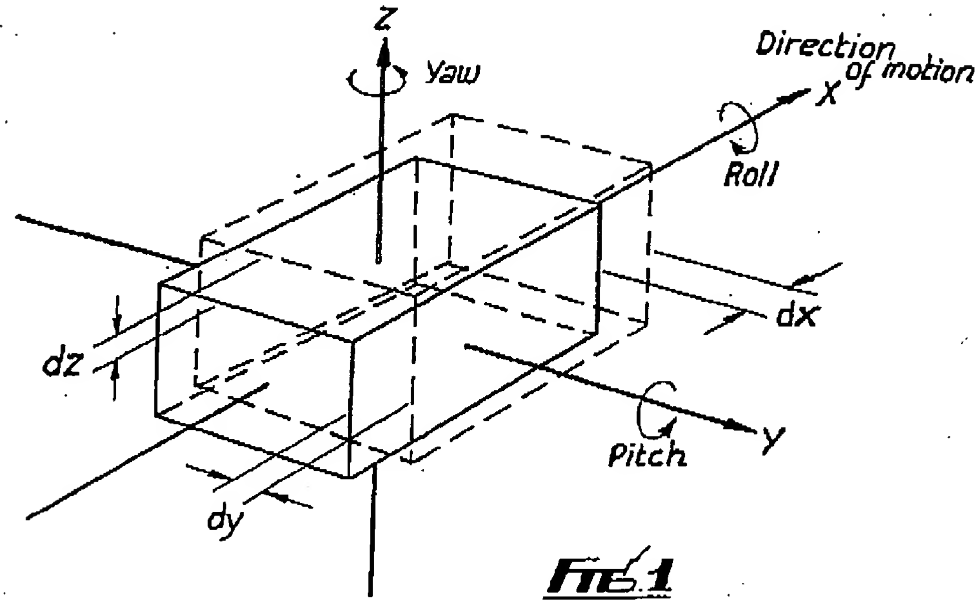

FIG. 1

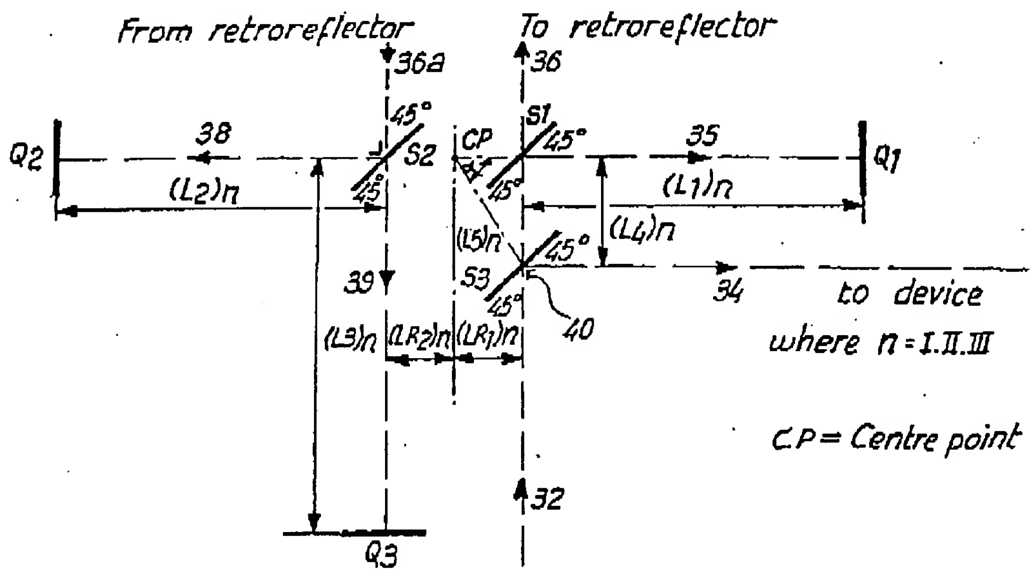

FIG. 4

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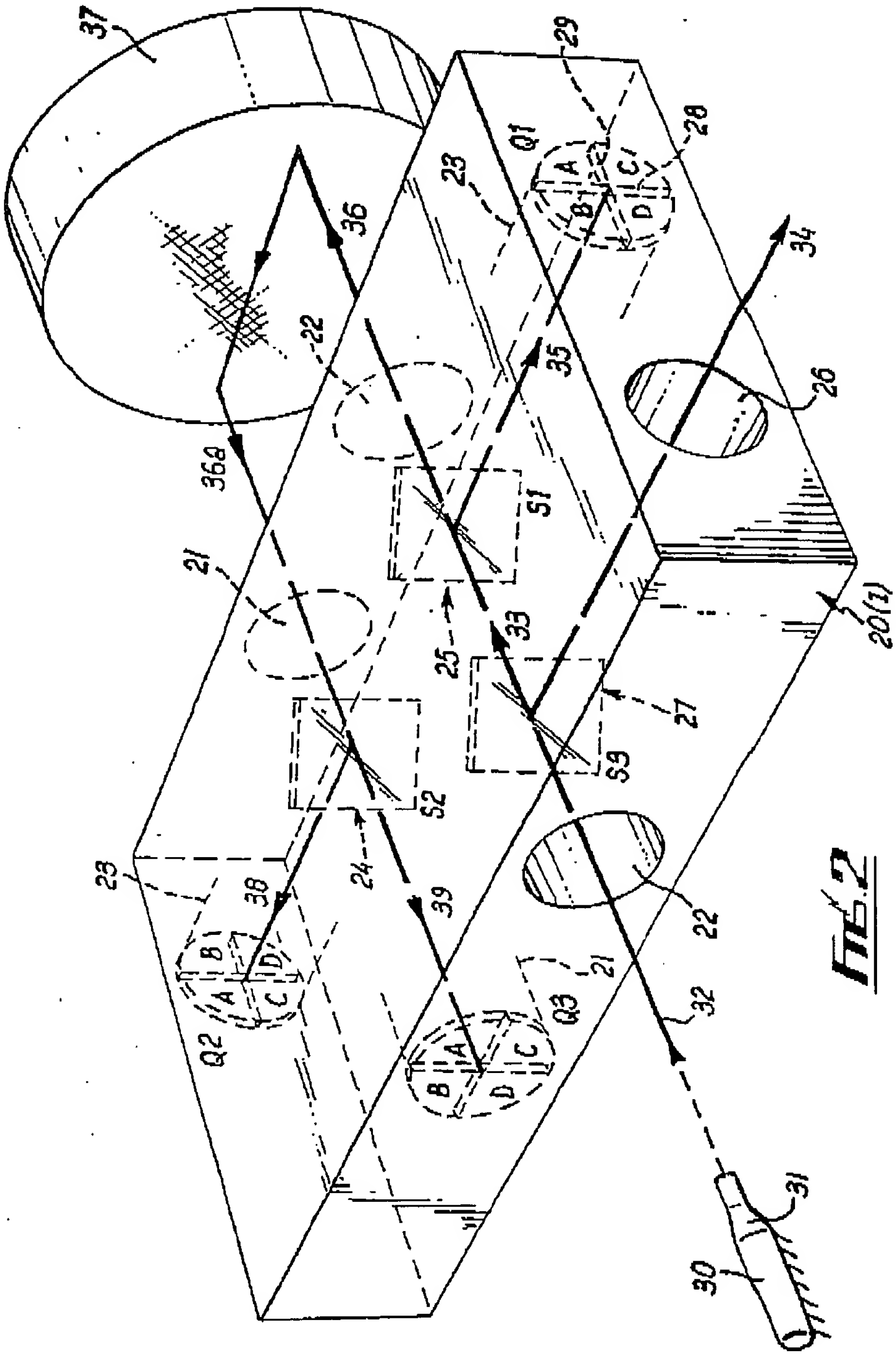

FIG. 2

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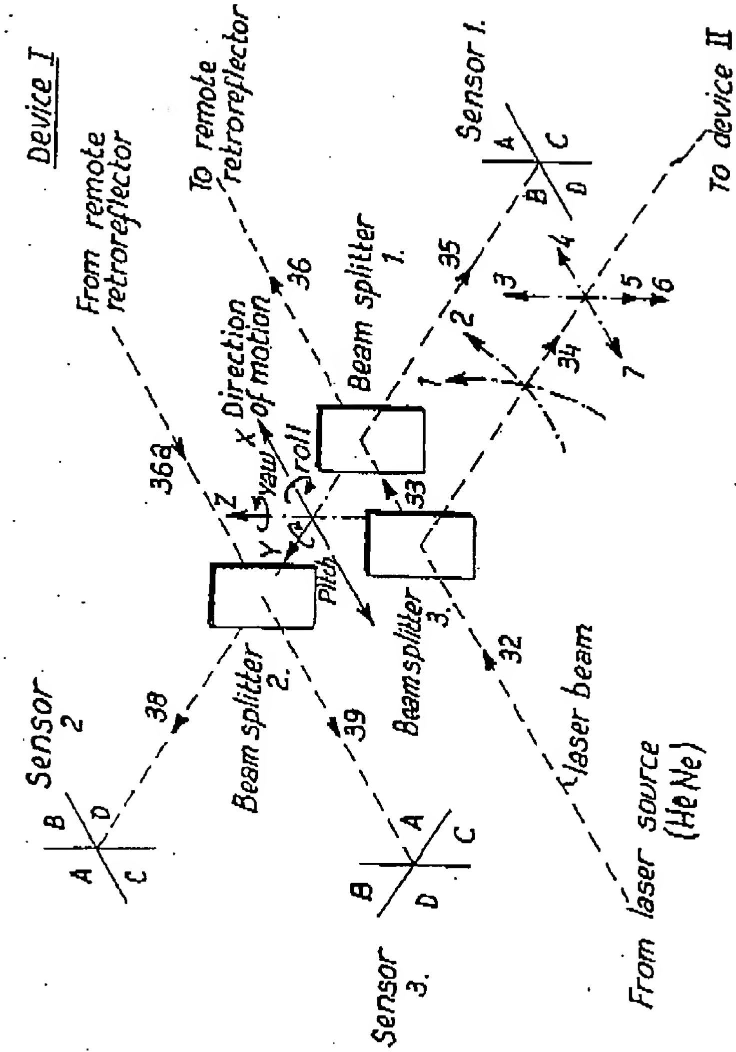

FIG. 3

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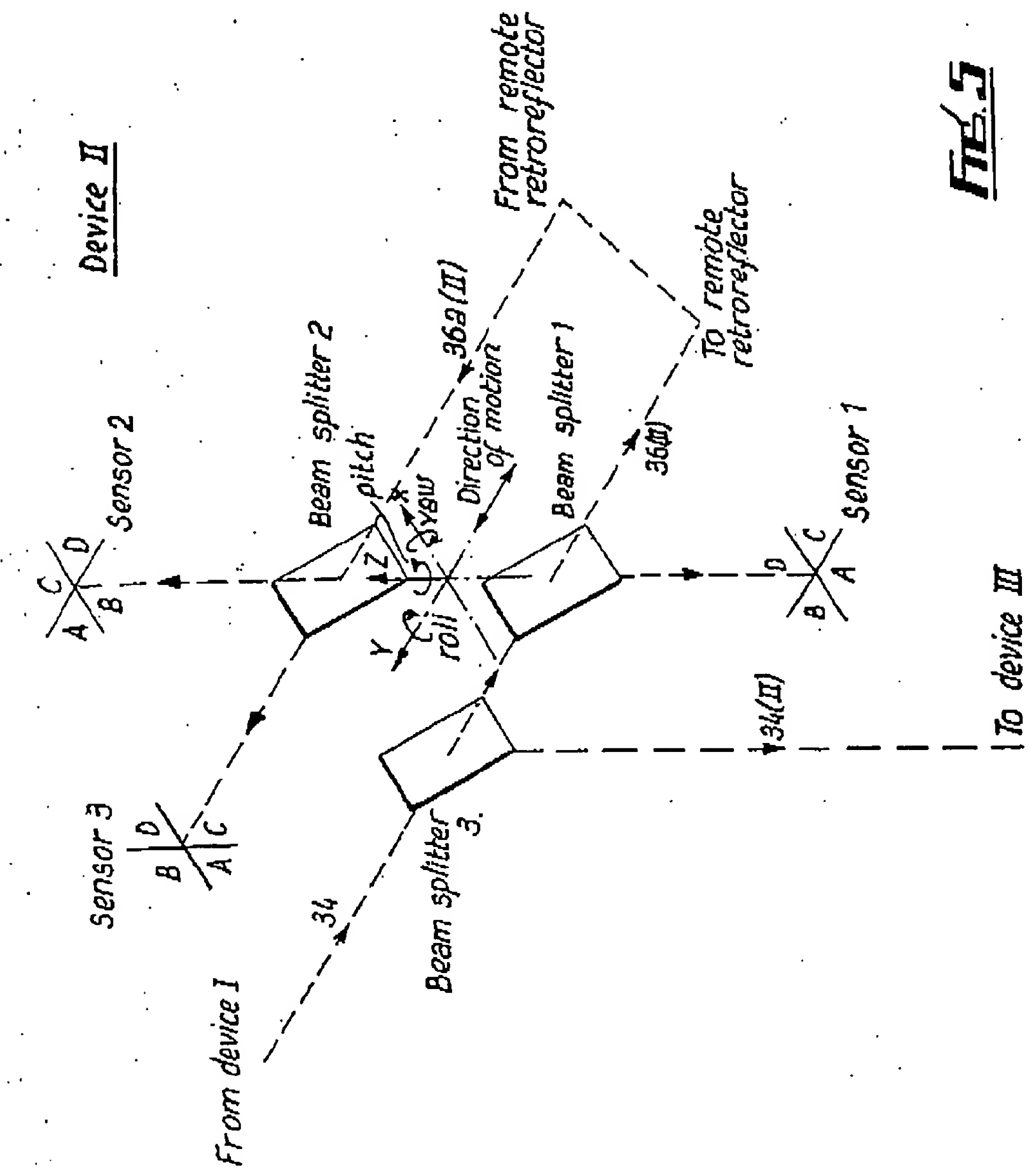

FIG. 5

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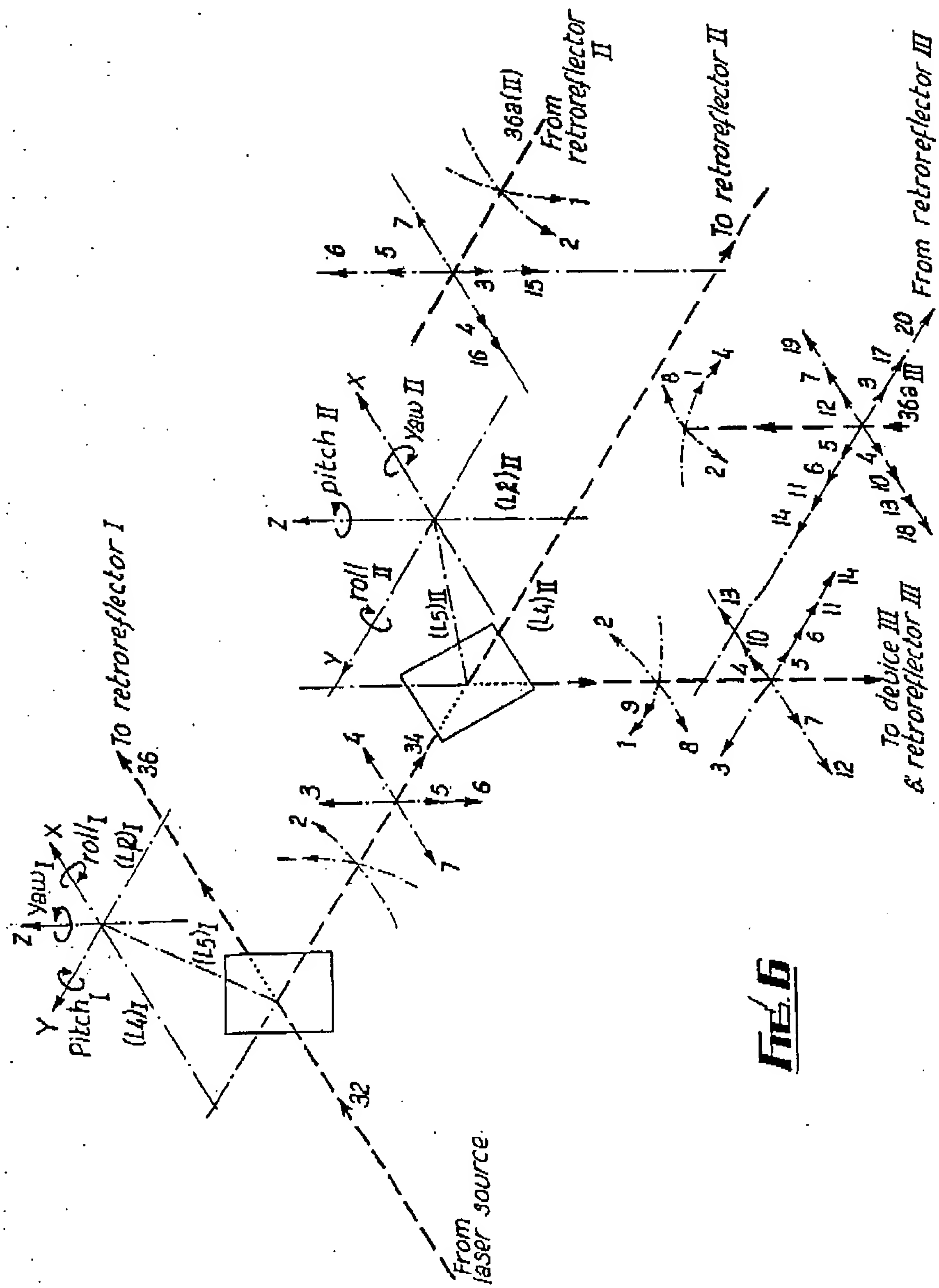

FIG. 6

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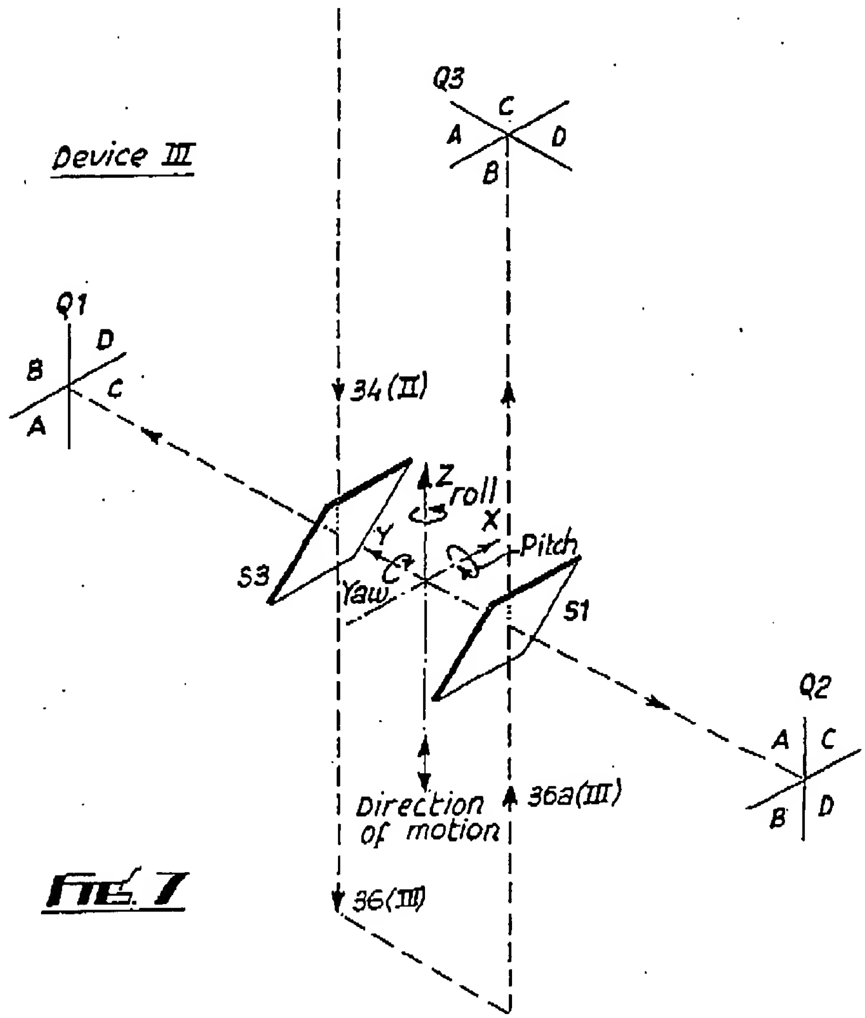

FIG. 7

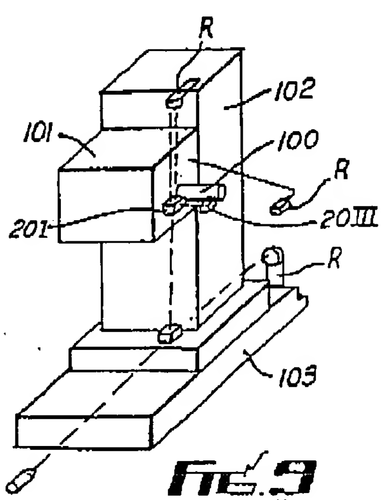

FIG. 9

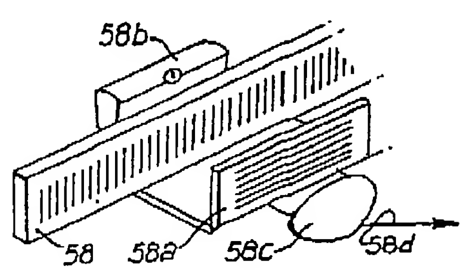

FIG. 10

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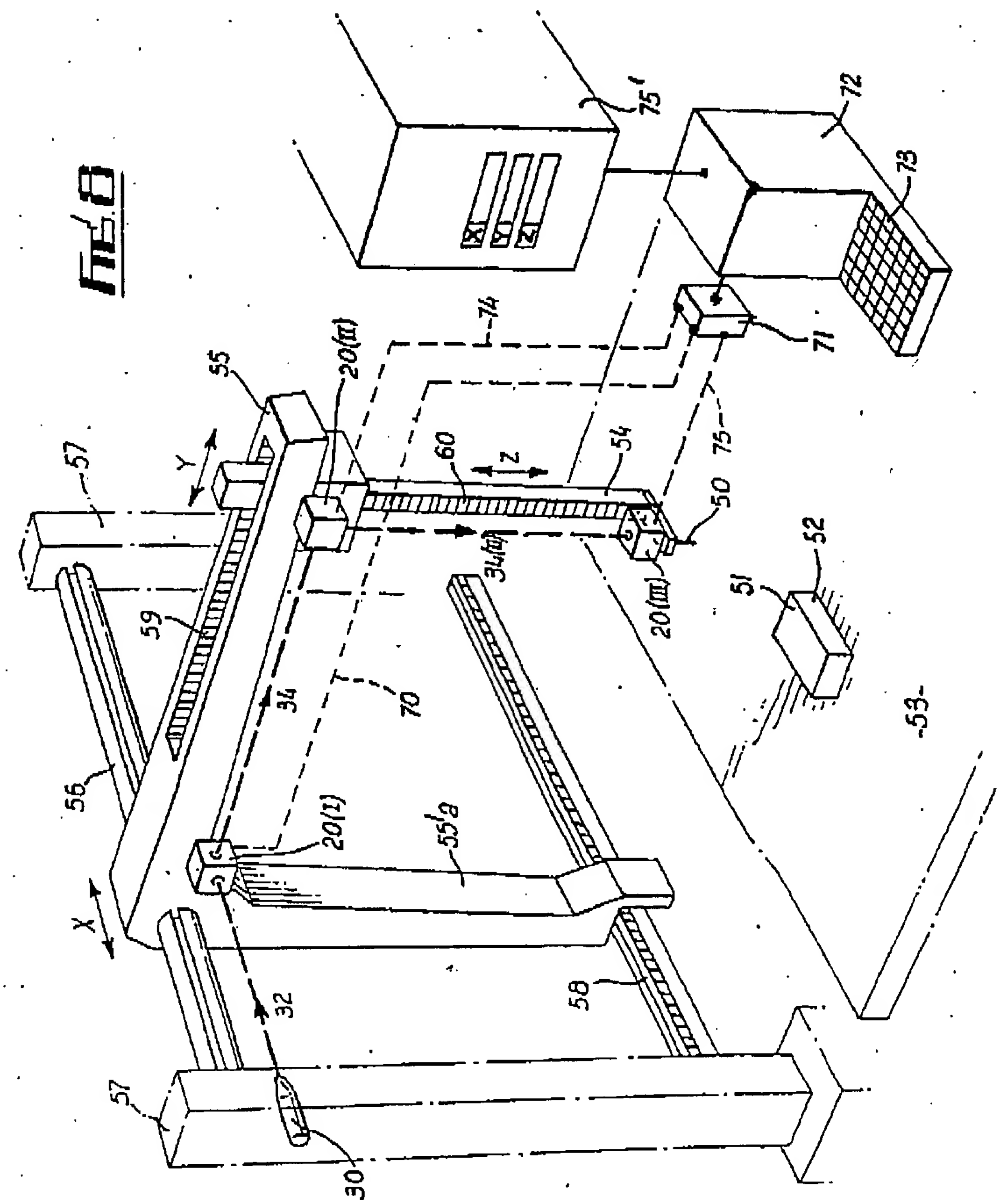
Fig 8



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Q1

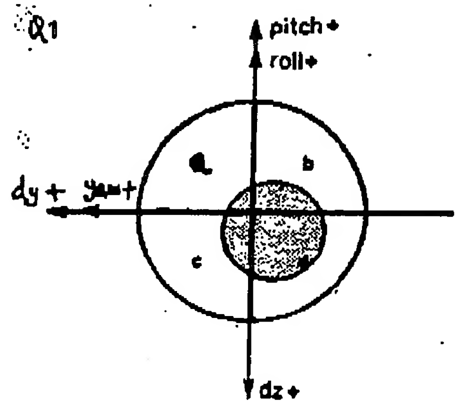
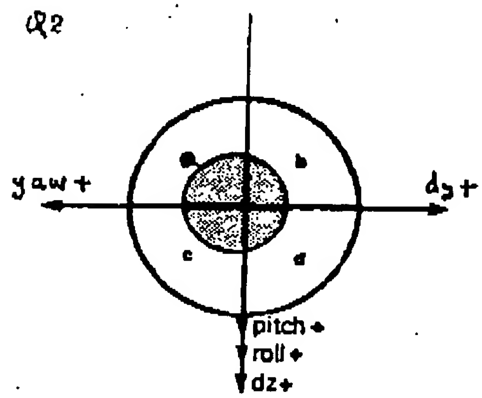
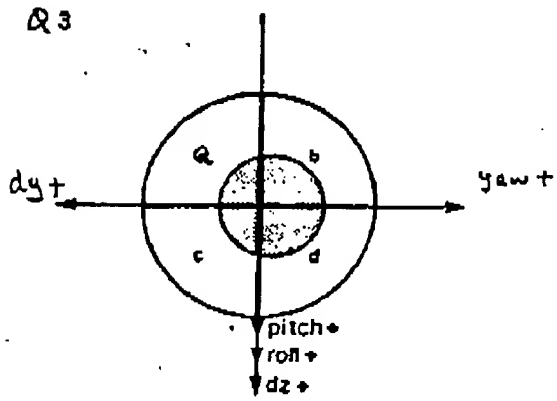


FIG 11

Q2



Q3



SPECIFICATION

Improvements in or relating to measurements of errors

This invention relates to the measurement of errors.

It is known to measure a linear positioning error using a laser interferometer. For example, if a machine tool slide is moved in the X direction, a laser is arranged to direct a beam of radiation along the X axis, through an interferometer and a Wollaston prism mounted on the slide to a fixed reflector device which reflects the beam back to the laser through the interferometer. The slide is then moved in the X direction in a series of steps of nominally known length and readings at the laser enable a comparison to be made between the nominal position and the actual position to determine the position error.

According to this invention a device for use in assessing the position of a body comprises means for movement with the body and adapted to receive a beam of electromagnetic radiation, said means being adapted to produce an indication of relative movement between the beam and the body in one or both of two directions transverse to the beam.

The directions may be at right angles to each other.

The directions may be at right angles to the beam.

The means may comprise a quadrant detector.

In one form the device comprises a first said means adapted to produce an indication of relative movement in one or both of two orthogonal directions at right angles to the beam, a second said means spaced a first distance from the first said means adapted to produce an indication of relative movement in one or both of the directions, a third said means spaced a second distance from the first said means adapted to produce an indication of relative movement in one or both of the directions, and means for directing a first beam to the first and second means, and means for directing a second beam to the third means, the first and second beams being parallel and independent of the movement, the first and second distances being different.

The first and second means may be parallel.

The invention also comprises a system of three such devices, the first said means of the three devices being mutually orthogonal.

The invention may be performed in various ways and two specific embodiments with possible modifications will now be described by way of example with reference to the accompanying drawings, in which:–

Figure 1 illustrates motional errors;
Figure 2 is a perspective view of a device according to the invention;
Figure 3 illustrates operation of the device;
Figure 4 further illustrates the operation;
Figure 5 illustrates operation of another such device;
Figure 6 illustrates operation of three such devices;
Figure 7 illustrates operation of a further such device;
Figure 8 illustrates use of the device in surface testing;
Figure 9 illustrates use of the device in boring, and
Figure 10 shows a fringe device.
Figure 11 is an illustration of position errors.

If a body moves nominally linearly in a direction, say the X direction, it is subject to six possible positional or motion errors, namely linear displacement errors δx, δy, δz respectively in the three orthogonal axes x, y, z and angular displacement errors of roll, pitch and yaw respectively about the x, y and z axes. This is illustrated in Fig. 1. This applies to a free solid body moving in space and, for example, to the slide of a machine tool moving in slideways.

The present arrangement enables five of the six errors to be measured simultaneously, the linear displacement error δx in the direction of motion being measured by a laser interferometer as described above.

The arrangement is based on a device as shown in Fig. 2. This comprises a rectangular block 20 having parallel through-bores 21, 22, an orthogonal through bore 23 intersecting bores 21, 22 at junctions 24, 25 and a further orthogonal bore 26 intersecting bore 22 at junction 27. Plane beam splitters S1, S2, S3 are located respectively at junctions 25, 24, 27. Radiation sensors Q1 and Q2 are located at the ends of bore 23 and radiation sensor Q3 is located at one end of bore 21.

Each radiation sensor comprises a quadrant detector having quadrants A, B, C, D separated by thin non-responsive orthogonal diametral portions 28, 29. When radiation falls on the quadrants, a voltage is developed at each quadrant dependent on the amount of radiation received and these voltages can be fed to a suitable monitoring apparatus and changes in the voltages can be used to measure linear and angular displacements.

A low powered helium laser 30 with a telescope 31 to increase the beam diameter produces a

coherent parallel beam 32 of electromagnetic radiation which is split by splitter S3 into through beam 33 and reflected beam 34 whose relative intensities may for example be in the ratio 3:7. Beam 34 passes along bore 26 to a similar device 20 as described later. Beam 33 is split by splitter S1 into reflected beam 35 and through beam 36. The relative intensities of beams 35 and 36 may be 7:3. Beam 35 falls on sensor Q1. Beam 36 is bent through two right angles by retroreflector 37 to form second beam 36a parallel to beams 32, 33, 36 which enters bore 21 at the opposite end from sensor Q3 and falls on splitter S2 which splits it into reflected beam 38, which falls on sensor Q2, and through beam 39 which falls on sensor Q3. The relative intensities of beams 38 and 39 may be in the ratio of 1:1 for example.

The beam splitters are mounted at 45° to the respective beams.

Fig. 4 is a plan view of Fig. 2 where CP is the mid-point between the centres of splitters S1 and S2, and the line between CP and the intersection 40 between the beams 34, 32 subtends an angle α with the beam 35. Distances are as indicated.

Fig. 3 is a perspective view of Fig. 2. If A_1 is the voltage at quadrant A of sensor Q1 and A_2 is the voltage at quadrant A of sensor Q2, and A_3 is the voltage at quadrant A of sensor Q3, and so on for quadrants B,C,D then the following equations apply:

$$[SV_1]_n = [(A_1)_n + (B_1)_n] - [(C_1)_n + (D_1)_n]mv$$
$$[SV_2]_n = [(A_2)_n + (B_2)_n] - [(C_2)_n + (D_2)_n]mv$$
$$[SV_3]_n = [(A_3)_n + (B_3)_n] - [(C_3)_n + (D_3)_n]mv$$
$$[SH_1]_n = [(A_1)_n + (C_1)_n] - [(B_1)_n + (D_1)_n]mv$$
$$[SH_2]_n = [(A_2)_n + (C_2)_n] - [(B_2)_n + (D_2)_n]mv$$
$$[SH_3]_n = [(A_3)_n + (C_3)_n] - [(B_3)_n + (D_3)_n]mv$$

where n = I, II, III for devices 20 reference I,II,III (devices 20(II) and 20(III) referred to later). In relation to device 20(I), Fig. 2 the following equations apply:

DEVICE 20(I):

for $[L_1]_I = [L_2]_I = [L_p]_I[mm]$
$[L_3]_I = 1.2[L_p]_I[mm]$
$[L_{R1}]_I = [L_{R2}]_I = [L_R]_I[mm]$
$[Z_1]_I = [Z_2]_I = [Z_3]_I = [Z]_I[$ = Z-axis displacement factor$]_I[{}^{\mu m}/_{mv}]$
$[Y_1]_I = [Y_2]_I = [Y_3]_I = [Y]_I[$ = Y-axis displacement factor$]_I[{}^{\mu m}/_{mv}]$
$\alpha = 60°$ [See Fig. 4]

then the errors in pitch, roll, yaw, z and y are as follows.

pitch error $[PITCH]_I = [(SV_2) - (SV_3)]_I[P]_I$[arc sec]
roll error $[ROLL]_I = [(SV_1) - (SV_2)]_I[R]_I - [PITCH]_I[{}^{LP}/_{LR}]_I$[arc sec]
z error $[\delta]_I = -0.5[(SV_1) + (SV_2)]_I[Z]_I[\mu m]$
yaw error $[YAW]_I = [(SH_1) + (SH_2)]_I[YW]_I$[arc sec]
y error $[\delta Y] = 0.5[(SH_1) - (SH_2)]_I[Y]_I[\mu m]$
where $[P]_I = [\text{pitch factor}]_I = [{}^{Z}/_{LP}]_I \times 10^3$
$[R]_I = [\text{roll factor}]_I = [{}^{Z}/_{LR}]_I \times 10^3$
$[YW]_I = [\text{YAW factor}]_I = [{}^{Y}/_{LP}]_I \times 10^3$

It will thus be seen that the displacement errors for pitch, roll, yaw, δz and δy can be calculated for movement in the x direction. It will be noted that L2 is not equal to L3; each of the sensors Q1, Q2, Q3 is responsive to errors δy, δz in two orthogonal axes y, z; the directions of the beams 36 and 36a are parallel.

In a modification sensor Q2 and splitter S2 are positioned so that sensor Q2 is at right angles to sensor Q1 with beam 38 rotated through 90° about beam 36a.

If the body is also moved in the y direction and assessment of errors in the position caused by this movement in the y direction are required to be measured, then beam 34 from device 20(I) is passed to a second device 20(II) such that beam 34 enters bore 22 of that device. This is schematically shown in Fig. 5 which shows the beam splitters and sensors (rectro-reflector omitted). The device 20(II) moves in the y direction. In this case the following equations apply:

DEVICE II

for $[L_1]_{II} = [L_2]_{II} = [L_p]_{II}[mm]$
$[L_3]_{II} = 1.2[L_p]_{II}$ [mm]
$[L_{R1}]_{II} = [L_{R2}]_{II} = [L_R]_{II}$ [mm]
$[Z_1]_{II} = [Z_2]_{II} = [Z_3]_{II} = [Z]_{II}[$ = Z-axis displacement factor$]_{II}[{}^{\mu m}/_{mv}]$
$[X_1]_{II} = [X_2]_{II} = [X_3]_{II} = [X]_{II}[$ = X-axis displacement factor$]_{II}[{}^{\mu m}/_{mv}]$
$\alpha = 60°$ (see Fig. 4)

then the errors are:

$[PITCH]_{II} = [(SV_2) - (SV_3)]_{II}[P]_{II} - [YAW]_{I}[\text{arc sec}]$

$[ROLL]_{II} = [(SV_1) - (SV_2)]_{II}[R]_{II} + [PITCH]_{II}[^{LP}/_{LR}]_{II} - [YAW]_{I}[\delta]_{I-II}] - [LR]_{I}[^1/_{LR}]_{II} - [\delta Y]_{I}[^2/_{LR}]_{II}[10^2] + [YAW]_{I}[LS]_{I}[^{0.84}/_{LR}]_{II} - [YAW]_{I}[\delta(I\rightarrow RrII) - [L_R]_{I}[^{0.5}/_{LR}]$ [arc sec]

$[\delta x]_{II} = 0.5[(SV_1) + (SV_2)]_{II}[x]_{II} + [YAW]_{I}[Lp]_{II}[5 \times 10.3] - [YAW]_{I}[\delta(I\rightarrow RrII) - (LR)_{I}][2.5 \times 10.3][\mu m]$

$[YAW]_{II} = -[(SH_1) + (SH_2)]_{II}[YW]_{II} - [PITCH]_{I}[\delta(I\rightarrow II)[^1/_{LP})_{II} + [PITCH]_{I}[L_R]_{I}[^{1.5}/_{LP}]_{II} - [ROLL]_{I}[L_R]_{I}[_1/_{LP} + [\delta_z]_{I}[^1/_{LP}]_{II}[2 \times 10^2] + [PITCH]_{I}[Lp]_{I}[^1/_{LP}]_{II} - [PITCH]_{I}[\delta(I\rightarrow RrII)(^{0.5}/_{LP})_{II}(\text{arc sec})$

$[\delta z]_{II} = 0.5[(SH_1) - (SH_2)]_{II}[Z]_{II} + [PITCH]_{I}[L_P]_{II}[5 \times 10^{-3}] - [PITCH]_{I}[\delta(I\rightarrow RrII) - (L_R)_{I}][2.5 \times 10.3][\mu m]$

where $[P]_{II} = [\text{PITCH factor}]_{II} = [^x/_{LP}]_{II} \times 10^3$

$[R]_{II} = [\text{ROLL factor}]_{II} = [^x/_{LP}]_{II} \times 10^2$

$[YW]_{II} = [\text{YAW factor}]_{II} = [^2/_{LP}]_{II} \times 10^2$

The position of the laser beam going out from DEVICE II could be seen in Fig. 4.

note: $[\delta(I\rightarrow II)]$ = distance from CP_I to CP_{II} (CP = centre point of the device)

$[\delta(I\rightarrow II)]$ = distance from CP_I to Retro reflector II

If the body is also moved in the z direction and assessment of errors in position caused by this movement are desired to be measured, the beam 34 (II) from device 20(II) passes to a third device 20(III) entering bore 22 thereof. This is schematically shown in Fig. 7. In this case splitter S2 is omitted from device 20(III) (retroreflector not shown). The following equations apply:

DEVICE III

for $[L_1]_{III} = [L_2]_{III} = [Lp]_{II}$ in [mm]

$[L_3]_{III} = 1.2[Lp]_{III}$ [mm]

$[L_{R1}]_{III} = [L_{R2}]_{III} = [L_R]_{III}[mm]$

$[X_1]_{III} = [X_2]_{III} = [X_3]_{III} = [X]_{III} = [\text{X axis displacement factor}]_{III} [^{\mu m}/_{mv}]$

$[Y_1]_{III} = [Y_2]_{III} = [Y_3]_{III} = [Y]_{III} = [\text{Y axis displacement factor}]_{III}[^{\mu m}/_{mv}]$

$\alpha = 60°$ [see Fig. 4)

then the errors are:

$[YAW]_{III} = -[(SV_2) - (SV_3)]_{III}[YW]_{III} + [YAW]_{I} - [PITCH]_{II}[\text{arc sec}]$

$[ROLL]_{III} = -[(SV_1) - (SV_2)]_{III}[R]_{III} - [YAW]_{III}[^{LP}/_{LI}]_{III} - [YAW]_{I}[\delta(I\rightarrow II) - [L_R]_{I} - [L_4]_{II} + [\delta(II\rightarrow III) - [L_R]_{II}[^1/_{LI}]_{III} + [PITCH]_{II}[\delta(II\rightarrow III) - (L_R)_{II}][^1/_{LR}]_{III} - [\delta y]_{I}[^2/_{LR}]_{III}[10^2] + [YAW]_{I}[L_3]_{I}[^{0.84}/_{LR}]_{III} - [ROLL]_{II}[L_R]_{II}[^1/_{LR}]_{III} + [\delta x]_{II}[^2/_{LR}]_{III}[10^2] - [PITCH]_{II}[L_4]_{II}[^1/_{LR}]_{III} - [YAW]_{I}[\delta(I\rightarrow II) - (LR)_{I} - (L_4)_{II} + \delta[II\rightarrow RrIII) - (LR)II][^{0.5}/_{LR}] {}_{II}[\delta(II\rightarrow RrIII) - (LR)_{II}][^{0.5}/_{LR}]_{III}[\text{arc sec}]$

$[\delta x]_{III} = 0.5[(SV_1) + (SV_2)]_{III}[X]_{III} + [YAW]_{I}[Lp]_{III}[5 \times 10^{-3}] - [PITCH]_{II}[Lp]_{III}[5 \times 10^{-3}] - [YAW]_{I}[\delta(I\rightarrow II) - [LR]_{I} - [l_4]_{II} + \delta(II\rightarrow RsIII) - (L_R)_{III}] [2.5 \times 10^{-3}] + [PITCH]_{II}[\delta(II\rightarrow RrIII) - [LR]_{II}](2.5 \times 10^{-3}][\mu m]$

$[PITCH]_{III} = -[(SH_1) + (SH_2)]_{III}[P]_{III} + [PITCH]_{I}[\delta(I\rightarrow II) - (LR)_{I} - (L_4)_{II} + \delta(II\rightarrow III) - [LR]_{II}][^1/_{LP})_{III} + [YAW]_{II}[\delta(II\rightarrow III) - (L_R)_{II}][^1/_{LP})_{III} + [ROLL]_{I}[LR]_{I}[^1/_{LP}]_{III} - [\delta z]_{I}[^2/_{LP}]_{III}[10^2] - [PITCH]_{I}[L_4]_{I}[^1/_{LP}]_{III} - [\delta z]_{II}[^2/_{LP}]_{III}[10^2] - [YAW]_{II}[L_5]_{II}(^{0.84}/_{LP})_{III} + [PITCH]_{I}[\delta(I\rightarrow II) - (LR)_{I} - [L_4]_{II} + \delta(II\rightarrow RrIII) - [LR]_{II}][^{0.5}/_{LP}]_{III} + [YAW]_{II}[\delta(II\rightarrow RrIII) - [L_R)_{II}][^{0.5}/_{LP}]_{III}[\text{arc sec}]$

$[\delta Y]_{III} = -0.5[(SH_1) - (SH_2)]_{III}[Y]_{III} + [PITCH]_{I}[Lp]_{III}[5 \times 10^{-3}] + [YAW]_{II}[Lp]_{III}[5 \times 10^{-3}] - [PITCH]_{I}[\delta(I\rightarrow II) - (LR)_{I} - [L_4)_{II} + \delta(II\rightarrow RrIII) - [LR]_{II}] [2.5 \times 10^{-3}] - [YAW]_{II}[\delta(II\rightarrow RrIII) - (LR)_{II}][2.5 \times 10^{-3}][\mu m]$

where $[YW]_{III} = [\text{yaw factor}]_{III} = [^Y/_{LP}]_{III}[10^3]$

$[R]_{III} = [\text{roll factor}]_{III} = [^x/_{LR}]_{III}[10^2]$

$[P]_{III} = [\text{pitch factor}]_{III} = [^Y/_{LP}]_{III}[10^2]$

Fig. 6 indicates the overall system with the following references (perceived errors):

1 : $[\mathrm{PITCH}]_{I}[\text{arc sec}]$
2 : $[\mathrm{YAW}]_{I}[\text{arc sec}]$
3 : $[\mathrm{ROLL}]_{I}[\mathrm{LR}]_{I}[5 \times 10^{-3}][\mu m]$
4 : $[\delta Y]_{I}[\mu m]$
5 : $[\delta Z]_{I}[\mu m]$
6 : $[\mathrm{PITCH}]_{I}[L_4]_{I}[5 \times 10^{-3}][\mu m]$
7 : $[\mathrm{YAW}]_{I}[L_5]_{I}[4.2 \times 10^{-3}][\mu m]$
8 : $[\mathrm{PITCH}]_{II}[\text{arc sec}]$
9 : $[\mathrm{YAW}]_{II}[\text{arc sec}]$
10 : $[\mathrm{ROLL}]_{II}[\mathrm{LR}]_{II}[5 \times 10^{-3}][\mu m]$
11 : $[\delta z]_{II}[\mu m]$
12 : $[\delta x]_{II}[\mu m]$
13 : $[\mathrm{PITCH}]_{II}[L_4]_{II}[5 \times 10^{-3}][\mu m]$
14 : $[\mathrm{YAW}]_{II}[L_5]_{II}[4.2 \times 10^{-3}][\mu m]$
15 : $[\mathrm{PITCH}]_{I}[\delta(\mathrm{I} \rightarrow \mathrm{RII}) - (\mathrm{LR})_{I}][5 \times 10^{-3}][\mu m]$
16 : $[\mathrm{YAW}]_{I}[\delta(\mathrm{I} \rightarrow \mathrm{RII}) - (\mathrm{LR})_{I}][5 \times 10^{-3}][\mu m]$
17 : $[\mathrm{PITCH}]_{I}[\delta(\mathrm{I} \rightarrow \mathrm{II}) - (\mathrm{LR})_{I} - (L_4)_{II} + \delta(\mathrm{II} \rightarrow \mathrm{RIII}) - (\mathrm{LR})_{II}][5 \times 10^{-3}][\mu m]$
18 : $[\mathrm{YAW}]_{I}[\delta(\mathrm{I} \rightarrow \mathrm{II}) - (\mathrm{LR})_{I} - (L_4)_{II} + \delta(\mathrm{II} \rightarrow \mathrm{RIII}) - (\mathrm{LR})\mathrm{II}][5 \times 10^{-3}][\mu m]$
19 : $[\mathrm{PITCH}]_{II}[\delta(\mathrm{II} \rightarrow \mathrm{RIII}) - (\mathrm{LR})\mathrm{II}][5 \times 10^{-3}][\mu m]$
20 : $[\mathrm{YAW}]_{II}[\delta(\mathrm{II} \rightarrow \mathrm{RIII}) - (\mathrm{LR})\mathrm{II}][5 \times 10^{-3}][\mu m]$

where δ = distance between two related devices
R_{II} = Retroreflector II
I = Device 20(I)

If errors related to movement in only one direction are needed then, for that direction, say the X-direction, in device 20(I) the splitter S3 and bore 26 can be omitted and devices 20(II) and 20(III) omitted. Similarly if only errors in two orthogonal directions (X, Y) are needed then device 20(III) is omitted and also splitter S3 and bore 26 from device 20(II).

The laser is fixed and the retroreflector(s) are fixed in relation to their light source i.e. the laser for device I; the device I for device II; the device II for device III.

It will be understood that the sensors Q1, Q2, Q3 in devices 20(II) respond to errors in the Z and X axes, and the sensors Q1, Q2, Q3 in device 20(III) respond to errors in the X and Y directions.

One example of use is shown in Fig. 8. In this case a probe 50 is for example to check or assess the shape of a surface 51 of article 52 on base 53 by traversing over and in contact with the surface 51. The probe is carried on a vertical arm 54 and can move up and down (Z axis) relative to arm 54. Arm 54 can move to and fro (Y axis) along the arm 55 which itself can slide (X axis) on rod 56 fixed between fixed uprights 57. Nominal X, Y and Z scales are shown at 58, 59, 60.

Device 20(I) is fixed to arm 55 adjacent rod 56, device 20(II) is fixed to arm 54 and device 20(III) is fixed to probe 50. Laser 30 illuminates all three devices 20(I), 20(II), 20(III). The twelve quadrants of the three sensors Q1, Q2, Q3 in device 20(I) are individually connected via separate lines 70 to analogue-to digital-converter 71 and are outputted to a computer 72 having a keyboard 73. Similarly the twelve quadrants of the three sensors in devices 20(II) and 20(III) are individually connected to the computer via converter 71 on lines 74, 75. The computer 72 is programmed to carry out on the input signals calculations as set out above to derive the cumulative positional errors δx, δy, δz. A visual display 75' shows the corrected coordinates X, Y, Z for the particular position of the probe.

A printer may be connected to the computer so that the positional values are printed out. The readings are independent of pressure and of relative humidity and of gravity. The readings may also be indicated on a visual display.

The apparatus is calibrated to provide a reference and the calibrations can be stored in the memory of the computer so that the errors used in calculating the values displayed at 75' are with regard to this reference.

In calibrating, for example for movement on the X-axis, the scale 58 is a graticule and another graticule 58a is carried by arm 55a. In known manner an optical device is used to observe moiré fringes produced between the two gratiucles to give a datum reading of the X position of the arm 55a and thus the probe 50 at a number of incremental positions along the scale 58. Thus, as the arm 55a is moved along the X axis from position zero on scale 58 to a first value say 0.010 cm. the number of fringes (say f) which move across the optical viewing mark can be counted. This number is stored in the computer. A laser interferometer as mentioned above is used to measure the positional error; thus the correct position may be 0.0011 cm. Thus a movement of f fringes gives a true position of 0.0011 cm. Errors at intermediate positions are calculated pro rata. This calibration is carried out say every 0.010 cm on scale 58. In use, as

shown in Fig. 11 showing the fixed graticule 58 and the graticule 58a which moves with arm 55a, the graticule 58a carries with it a light source 58b and photo detector 58c so that a signal passes to the counter on line 58d each time the light is interrupted by a fringe moving across the field of view. The fringes can thus be counted by the computer. The nominal position on scale 58 (X-axis) is thus ascertained by the computer from its memory.

The error in the X-axis position caused by movement in the Y and Z axes is then obtained as δx_{III} from device 20(III). Thus if the nominal position is 1.000 cm and δx_{III} is +0.001 cm, the X display at 75 will be 1.001 cm. This X value must then be corrected by the error in the X coordinate caused by movement in the X axis as measured by the laser interferometer. The device 20(I) indicates the errors δy, δz introduced by the movement on the X-axis.

Similarly a graticule is carried by arm 54 and cooperate with graticule scale 59 and an optical device as above to give a Y position while device 20(II) gives an indication of errors δx, δz produced by movement in the Y direction. A similar calibration is done in the Z direction using a graticule movable with the probe and the device 20(III) indicates errors δx, δy produced by movement in the Z direction.

Similarly, $[\delta y]_{III}$ gives the error in the Y axis produced by movement in the X and Z axes and the Y-axis display at 75 is calculated accordingly. This value must be corrected by any Y-axis error caused by movement on the Y axis and measured by a laser interferometer.

Similarly, $(\delta z)_{II}$ gives the error in the Z axis produced by movement in the X and Y axes and the Z-axis display at 75 is calculated accordingly. This value must be corrected by any Z-axis error caused by movement on the Z axis and measured by a laser interferometer.

The errors of pitch, roll and yaw, in addition to enabling calculation of δx, δy, δz errors as above, also enable corrections to be made, using known calculations, in respect of the orientation of a probe or tool which is moved on the Y axis, or on the X and Y axes, or on the X, Y & Z axes. The beam from laser 30 and the device 20(I) are positioned such that the beam is at the centre of all three detectors with the arm 55 at both the beginning and end of scale 58. This fixes the X-axis both in space and in relation to the devices 20. The device 20(II) is secured to arm 54 in such a manner that the radiation from beam 34 is at the centre of all three quadrants of device 20(II) at both the beginning and end of scale 59. This sets the Y axis for the devices 20. The device 20(III) is secured to the probe in such a manner that the radiation from beam 34 (II) is at the centre of all three detectors in device 20(III) with this device both at the beginning and end of scale 60. This fixes the Z axis for the detectors in relation to the XY plane of the devices.

Although the devices 20 enable calculation of errors caused by movement on the X, Y, X axes, it is possible that these axes are not orthogonal and therefore known squareness error procedures are carried out to measure errors produced by non-squareness of axes (between X and Y axes and between Z axis and XY plane) and these errors are also stored by the computer memory and are taken into account by the computer in displaying the X,Y,Z values at 75. It will be understood that if ΔX, ΔY, ΔZ are the errors measured by the laser interferometer in the X,Y & Z axes, and the display at 75 is X1, Y1, Z1 then the true position of the probe in relation to the scales 58, 59, 60 is

$$X_1 + \Delta X_1, Y_1 + \Delta Y, Z_1 + \Delta Z_1$$

Fig. 9 shows a floor mounted horizontal boring machine in which a tool 100 is mounted for movement in the Z axis in block 101 which can slide in the Y axis on pillar 102 which can move in the X axis on the base 103. In this case device 20(III) is movable with the tool housing.

The device can be used in assessing the error in a horizontal boring mill and can be used to provide an indication of the orientation of the tool tip to a desired direction.

In plotting the contour of for example the top surface or side surface of the object 52, the probe would be moved in an array of paths. Thus the probe would be placed at a fixed position on the X axis, moved across the object surface taking readings at a plurality of equispaced locations; and this is then repeated for a number of equispaced positions across the object in the X direction. In the case of a side surface, the probe would move in the X and Z directions. From a consideration of the contours of the top and side, an assessment can be made of whether the top is at right angles to the side or what is their angular relationship at each test location.

Instead of using a laser interferometer, other methods could be used to measure the position error in one direction. In summary to measure errors of motion of a body which is moving in one axis, device 20(III) can be used alone. The information obtained from the (3 × 4) quadrants of the device can be combined to produce information of pitch, roll, yaw, and straightness errors (vertical and horizontal displacements) as stated for device 20(I). In this case, axial displacement error (positioning error) should be measured separately (by using any method available e.g. laser interferometer) to complete the measurement.

To measure simultaneously errors of motion of moving body in space which is moving in two-

axes, devices 20(II) and 20(III) can be used in combination. In this case, two axial displacement errors (positioning errors) and one squareness error (between both axes) should be measured individually before taking the information from (2 × 3 × 4) quadrants of both device. The (2 × 3 × 4) readings can produce information of motional error of the body in space (as stated for device 20(I) and device 20(II)) in their combination with positional and angular errors measured separately.

Furthermore, when devices 20(I), 20(II), 20(III) are used together in their specific configuration in XYZ axes, the combination of their information with positional errors in X, Y, Z axes and the squareness of Y axis towards X axis, and Z axis towards XY plane, can produce information required for calibration of volumetric errors within the working zone of the measured moving body.

In use of the device or devices, the cumulative error signals may form part of a feedback connection to a control device or arrangement so that a movable element, for example a machine slide of a machine tool, is brought to a predetermined position. Thus, in the case of the probe, in addition to or alternative to indicating the actual probe position, there may be a control device responsive to the error signals to bring the probe to a predetermined position.

Fig. 11 indicates positional errors at the three quadrants as a result of changes dy, dz and in roll, pitch and yaw.

CLAIMS

1. A device for use in assessing the position of a body comprising means for movement with the body and adapted to receive a beam of electromagnetic radiation, said means being adapted to produce an indication of relative movement between the beam and the body in one or both of two directions transverse to the beam.
2. A device as claimed in Claim 1, in which the directions are at right angles to each other.
3. A device as claimed in Claim 2, in which the directions are at right angles to the beam.
4. A device as claimed in any preceding claim, in which said means comprises a quadrant detector.
5. A device as claimed in any preceding claim, comprising a first said means adapted to produce an indication of relative movement in one or both of two orthogonal directions at right angles to the beam, a second said means spaced a first distance from the first said means adapted to produce an indication of relative movement in one or both of the directions, a third said means spaced a second distance from the first said means adapted to produce an indication of relative movement in one or both of the directions, and means for directing a first beam to the first and second means, and means for directing a second beam to the third means, the first and second beams being parallel and independent of the movement, the first and second distances being different.
6. A device as claimed in Claim 5, in which the first and second means are parallel.
7. A device as claimed in Claim 5 or Claim 6, in which each of the first, second and third means comprises a quadrant detector.
8. A device for use in assessing the position of a body substantially as herein before described with reference to Fig. 2 of the accompanying drawings.
9. A system comprising three device as claimed in any proceeding claim, the first means of each of the devices being mutually orthogonal.
10. A system for use in assessing the position of a body substantially as herein before described with reference to Fig. 8, or Fig. 9, of the accompanying drawings.
11. A position assessing device however defined.

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